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# IGY BULLETIN

*A monthly survey of plans, activities and findings in geophysics—with emphasis on United States contributions to the International Geophysical Year, International Geophysical Cooperation–1959, and similar international endeavors including the World Magnetic Survey, the Year of the Quiet Sun, the Indian Ocean Expedition, the Antarctic research program, and space exploration and research. Preparation and publication of the* Bulletin *is supported by the National Science Foundation.*

## US Antarctic Meteorology during the IGY

### Part II: Weather Central and Hallett and Byrd Stations

*This is the second portion of a report based on a series of articles prepared by US Weather Bureau meteorologists who took part in the IGY Antarctic program. The series originally appeared in* Weatherwise, *a publication of the American Meteorological Society. Part I, covering the work at Little America and Amundsen-Scott South Pole IGY Stations, appeared in* Bulletin No. 53, *November 1961.*

#### The Weather Central at Little America

During the planning of the IGY Antarctic Program, in early 1955, the need for a weather central in the Antarctic was recognized. Air operations and over-snow traverses required accurate weather forecasting and analysis to assure maximum safety for operating personnel. The weather central would also serve as a clearing house for all raw Antarctic weather reports. Such reports would be screened at the Antarctic weather central and then transmitted by radio to other weather services in the Southern Hemisphere to help improve and extend their weather analyses and forecasts.

The international IGY coordinating body, CSAGI, asked the United States to accept the responsibility of operating an Antarctic weather central during the IGY. The US National Committee accepted and plans were made to locate the IGY Antarctic Weather Central at Little America V. In addition to US meteorologists, representatives from Argentina, Australia, France, New Zealand, South Africa, and the USSR participated in the program.

Before the IGY Weather Central could go into full operation, it was necessary to activate the Antarctic communications network, consisting of a "mother-daughter" relay system (Fig. 1). On a prearranged schedule, a mother station collected weather reports from a number of daughter stations, then relayed these reports to the radio central at McMurdo Sound, where they were again collected and relayed to the Weather Central. After a delay owing to damage of the McMurdo antenna field by a blizzard in mid-May of 1957, the mother-daughter network went into full operation in late June. In addition to receiving weather reports from Antarctic stations on a regular schedule, weather data broadcasts from Southern Hemisphere countries were also intercepted at Weather Central.

The Weather Central analysis program included preparation of four surface charts; two 700-, 500-, and 300-mb constant-pressure charts; and one 50-mb constant-pressure chart per day. Pseudo-adiabatic charts

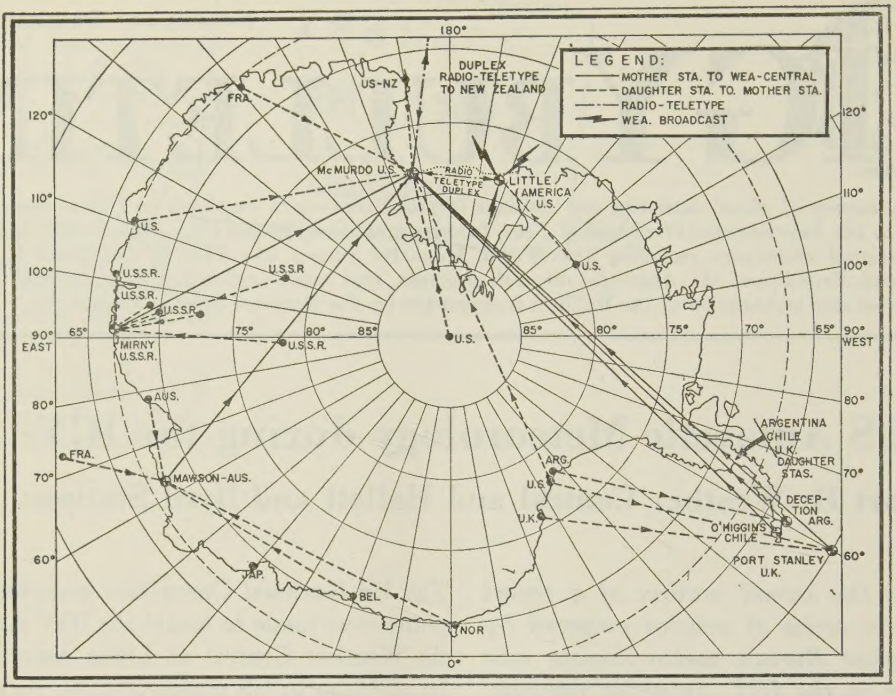


Fig. 1. *Antarctic "Mother-Daughter" Communications Network.*

were plotted for all Antarctic upper-air reports, and vertical time sections of temperature, wind, etc., were analysed for nine Antarctic stations.

Antarctic data collectives prepared by Weather Central personnel were broadcast four times daily, and upper-air and surface analyses were transmitted once a day. On June 3, 1957, the first weather maps ever transmitted from the Antarctic continent were sent from Little America Station to Washington, D. C., via radio facsimile.

In addition to the analysis programs, special research studies were made on Antarctic weather and atmospheric circulation features. One of many interesting Antarctic weather situations occurred during the middle of May 1957. On May 11, a surface temperature of —1° C (+30° F) was recorded at Little America while, on the same day, the surface temperature fell to —74° C (—100° F) at the South Pole. The temperature at Little America had risen 24° C with the approach of an occlusion on May 9. (An occlusion is a composite front formed when a cold front overtakes a warm front.) Although the temperature fell 11° C on the 10th, it rose 18° C, to the high of —1° C, with the passage of another frontal system on the 11th. During this same period at the South Pole, clear skies and light winds permitted temperatures to drop steadily, reaching the minimum of —74° C on the 11th.

On May 12, an upper-air frontal system caused cloudiness and precipitation as it moved across the Pole, and surface temperatures rose 22° C in a 24-hour period. Since a similar combination of meteorological events did not occur again during 1957, this 73° C (over 130° F) temperature gradient between the Pole and Little America was the greatest encountered during the year.

Vertical time sections for the Little America and the South Pole stations for the period May 7–19 reveal that it is possible for fronts to penetrate deep into the interior of the Antarctic continent. However, experience showed that only the more

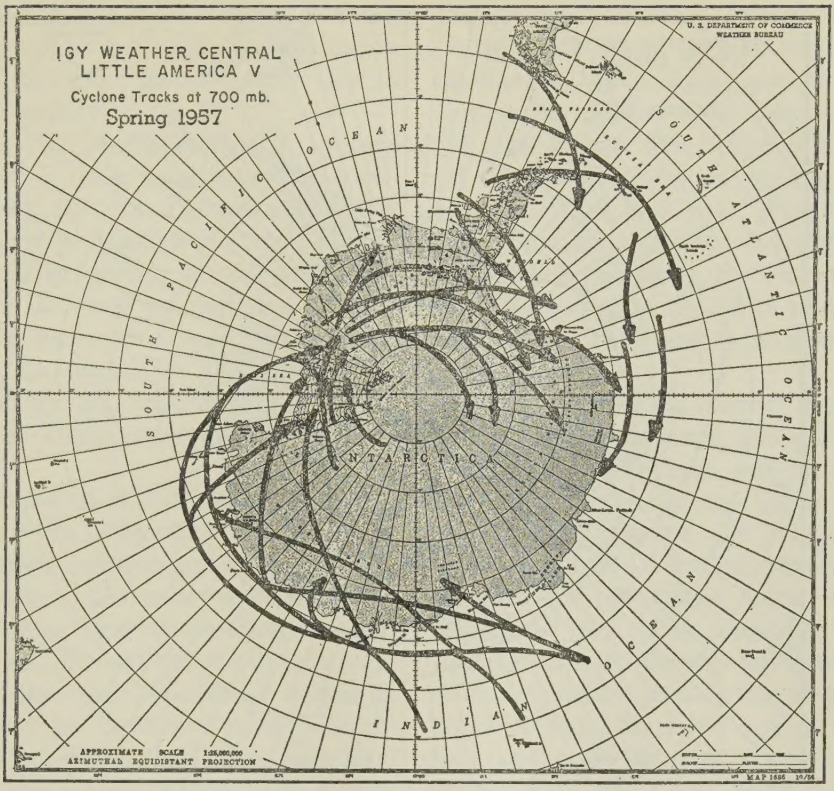


Fig. 2. *Cyclone Tracks at 700-mb Level over Antarctic, Autumn 1957. Because of the high average elevation of the Antarctic interior, weather at the 700-mb pressure level (about 10,000 feet) is very nearly surface weather for much of the continent. (Prepared by V. I. Rastorguev and J. A. Alvarez, Antarctic Weather Central, 1957.)*

intense frontal systems are capable of maintaining their identity all the way to the Pole. Temperature contrasts across the fronts weaken as the air mass is modified during its movement over the extensive Antarctic ice sheet. Generally, only the upper remnants of a frontal system are evident by the time they reach the Pole, but they are still sufficiently intense to cause cloudiness and precipitation.

Preliminary atmospheric-circulation studies made by V. I. Rastorguev (USSR) and J. A. Alvarez (Argentina), who worked at the Weather Central in 1957, indicate that the interior of West Antarctica may be a more stormy region than the high interior of East Antarctica. As shown by the 700-millibar cyclone tracks for autumn and spring of 1957, (Figs. 2 and 3, respectively) a major storm path exists from the Ross Sea through Marie Byrd Land and the Ellsworth Highland into the Weddell Sea. Cyclones moving along the coast of East Antarctica usually did not penetrate deeply into the interior until they reached Wilkes Land. The presence of a semi-permanent anticyclone over the high interior plateau tended to block the entry of the cyclones until they had passed the 90° E meridian.

The comparative freedom of the interior of East Antarctica from storms and cloudiness helps make it one of the coldest places on earth (see Fig. 1, *Bulletin No. 53*). Because of the high elevation of this region, averaging 10,000 feet above sea level, clear skies permit a large amount of heat to escape from the surface through the dry, transparent atmosphere. Record low tem-

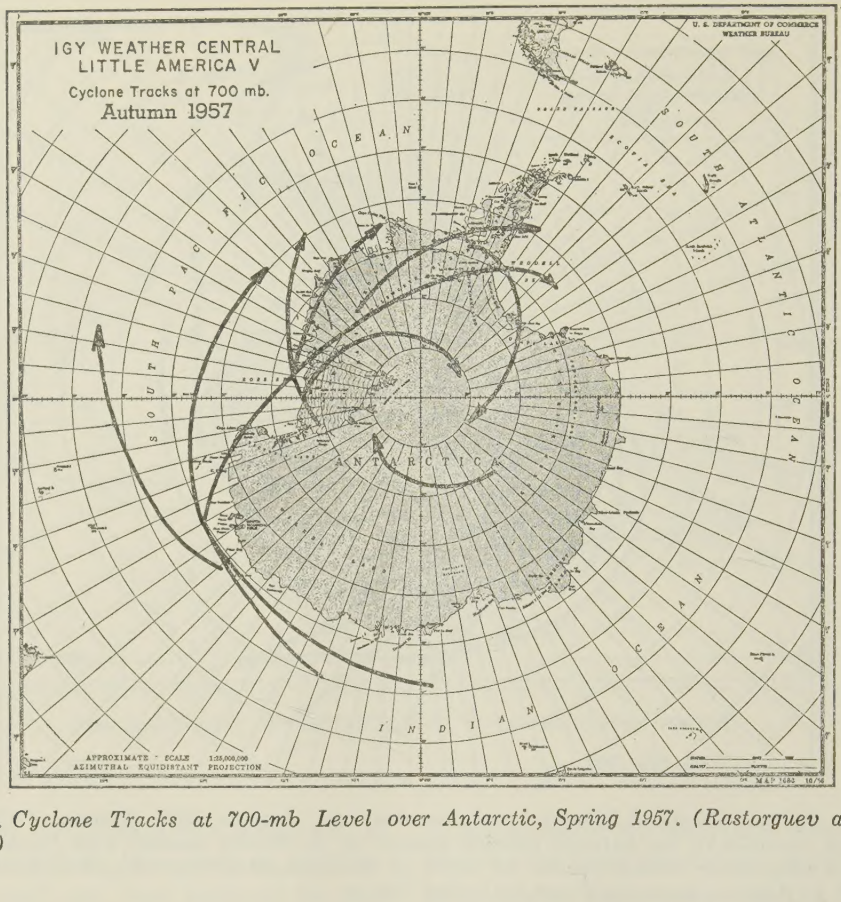


Fig. 3. *Cyclone Tracks at 700-mb Level over Antarctic, Spring 1957. (Rastorguev and Alvarez.)*

peratures have been reported by the USSR stations located in this high, interior plateau area: the lowest to date was —88.3° C (—126.9° F), at Vostok (78° S, 107° E, elevation 11,200 feet), August 24, 1960.

In addition to the frequent radio fadeouts, operational problems resulted from the limited working space, confinement, and rigorous climate. Despite the often severe working conditions at Little America Station, however, much valuable experience was gained and substantial results were achieved by the IGY scientists of the first Antarctic Weather Central.

## Hallett Station

Located on Cape Hallett, a flat, barren promontory, slightly above sea level at the southern end of Moubray Bay and at the foot of the Admiralty Range on the western margin of the Ross Sea, Hallett Station was operated jointly by a small party of United States and New Zealand personnel during the IGY. Although Hallett had a meteorological staff of only four, its weather-observation program was nearly as extensive as those of the larger stations. Because of its location on the air route from New Zealand to the US Naval Air Facility at McMurdo Sound, Hallett Station has served, both during and since the IGY, as a key point in flight planning and navigation for this vital route.

Two years of IGY climatic records were obtained at Hallett Station. The mean annual temperature for each of these years—1957 and 1958—was +4.6° F, and the extreme temperatures were +42° F and —44° F. The annual temperature regime shows an anomaly in June, when cooling is temporarily halted. July is the coldest month,

just a little colder than August, and the mean temperature in the Hallett region gradually rises from the mid-winter low to a peak in January.

In June, the stormiest month, average wind speed is at a maximum. The mean wind speed in 1957 was 17 knots and in 1958 it was 15 knots. Masked in these averages are alternating periods of calm or near-calm days, followed by periods of strong winds. The mean wind speed for October was only 12 knots but, in 1957, a three-day storm late in this month had sustained winds of 80 knots and a peak gust of 99 knots.

The location of Hallett Station, oriented NE-SW at the seaward end of a "V"-shaped valley, is important in considering its wind regime. The valley and the water-ice floor widen toward the Ross Sea and the northeast. Beyond the southwestern extremity of the valley, the terrain begins its gradual rise to the ice-covered Victoria Land plateau, where elevations reach 8000 to 10,000 feet a few hundred miles inland. This topographic setting favors the observed constancy of wind direction—prevailingly from the southwest—at Hallett Station.

A notable deviation from the annual prevailing wind direction occurs in December. Beginning in late November and continuing into December of 1958, there was a distinct sea breeze, resulting in a prevailing northwest wind. Sea breeze, tide, and ice movement were rather closely related during this period. Shortly after the onset of the sea breeze and the beginning of the diurnal tide, loose ice began drifting from the Ross Sea into Moubray Bay.

The precipitation pattern at Hallett Station is closely connected with the wind and with general storm conditions. During the IGY, a period of strong winds always appeared to follow a snowfall, and a general temperature rise either preceded or accompanied the fall of snow. As is usually the case, it was extremely difficult to determine accurately when the falling snow ended and the blowing snow began. Examination of the precipitation record for the two IGY years discloses a late-summer—early-fall maximum, with another near-maximum during the early winter. This indicates a continental type of precipitation regime, but with some maritime influences. With respect to this conclusion, the storm of October 20–22, 1957, mentioned above, appears anomalous. It is interesting to note that 1958 had approximately 25% less precipitation than 1957.

During periods of strong winds, snow cover on the ground was sparse. Except for drifts around buildings and in doorways, and snow coming through small cracks in the walls, snow cover was not too great a problem at Hallett Station. Movement out-of-doors during periods when snow was driven by high winds, however, was extremely difficult. During the October 1957 storm, movement outside was virtually impossible. Early warming had softened the bare and rocky ground. Flying debris included small rocks and gravel, and windward-facing surfaces were abraded severely. Wooden objects commonly took on a granular appearance and a windshield was so pitted that replacement was necessary. In 1958, there were three storm periods when stout line was strung from building to building for the safety of personnel, and a plan for checking in and out via the "teletalk system" was also initiated.

The prediction of severe storms seemed to hinge upon the appearance, at the 500-millibar level, of a northeasterly air flow. This local forecasting guide was subsequently studied further and expanded to include the "rule of thumb" that the depth of the northeasterly flow would be an indication of the severity and duration of the storm—the deeper the flow, the stronger and longer-lasting the storm.

An emergency landing strip was also maintained on floating ice near Hallett Station. During the last half of 1958, there never appeared to be any danger of the strip moving out to sea. The maximum

thickness of the ice was about 76 inches, and the last measurement, about mid-December, showed an upper layer of 26 inches of dry ice above 40 inches of wet ice.

As in nearly all mountainous regions, some unusual cloud formations were observed. The clouds at Hallett were "lenticulars." The most spectacular of this variety, consisting of many layers of lens-shaped masses, was seen over Cape Roget. In appearance, it was similar to the one reported in 1958 over Mt. Rainer, by R. J. Reed. From the viewers' vantage point, the Hallett cloud appeared dark, but this may have been due to available light conditions, since other lenticulars were the usual white. It was noted during 1958 that Cape Roget seemed to be a favored location for the formation of these clouds. Others formed occasionally as "scarf" clouds around Mt. Herschel, about 17 miles directly west of the station. Mt. Herschel reaches a maximum height of about 11,500 feet above sea level, while elevations in the Cape Roget area do not exceed 4000 feet.

Towering cumulus clouds also would form over this high region (Cape Roget) to the north. Bases of these clouds were estimated at about 4000–5000 feet, with tops close to 15,000 feet. No direct reports regarding heights of the tops were available, however. The trail party from the interior, in February 1958, reported towering columnar cumulus clouds that formed rapidly over snow-free areas.

The final six months of the IGY period produced some interesting solar-radiation data. During late November 1958, radiation received over approximately a 20-hour daylight period with nearly clear skies was found to be about the same as that received at a Southwestern United States desert station under about the same conditions—800 langleys per day (1 langley equals one gram-calorie/cm$^2$). The radiation instruments were located in an area where the surface varied—i.e., new snow, old snow, bare ground—and albedo measurements for the various types of surface cover at Hallett Station agree with the generally recognized normals for such surfaces.

Soil temperatures at Hallett were taken at depths of 10 and 50 centimeters. The thermohms, buried close to the solar-radiation equipment, were completely drifted over by July 1958. The first months of record give temperatures under a gradually deepening blanket of snow, which reached a thickness of five feet before being bulldozed off in August. The removal of this blanket resulted in a sharp temperature drop. At 50 cm, temperatures approached the freezing point but did not rise above it, indicating that permafrost (permanently frozen ground) existed in the measurement area at this depth below the surface.

In December 1958, a thermograph was installed over a moss area east of the camp to measure the temperature environment of these plants. The sensing unit, approximately 1/4-inch above the moss surface and perpendicular to the prevailing southwest wind, recorded a temperature high of 68° F. In April 1959, a balloon-borne radiometer program, conducted jointly with similar studies at the South Pole Station, was begun in order to measure radiative cooling during the polar night.

The results of these and other observations made at Hallett Station, including some instituted since the IGY period, may be of considerable ultimate significance, both in basic meteorological studies and in providing better weather advice for traffic between Antarctica and New Zealand.

## Byrd Station

The broad, wind-swept snow plateau of Marie Byrd Land, at 80°S, 120°W, is the site of Byrd IGY Station. One reason for the choice of this location was to investigate the puzzling atmospheric-pressure surges that occur in West Antarctica. First noted and described by G. C. Simpson, meteorologist with the British Antarctic Expedition of 1910–13, they were thought to originate at about 80°S, 120°W, and move

northwestward across the Ross Ice Shelf. Prior to the IGY, Antarctic data were not sufficient to determine the extent and causes of these pressure surges but the accumulation of additional data, begun with the IGY and still continuing, may shed further light on this problem.

Shortly after Byrd Station was established, seismic soundings showed that the relatively flat snow surface upon which the camp rested is the top of an 8000-foot thickness of ice, although this surface is only about 5000 feet above sea level. Thus, the bedrock surface is approximately 3000 feet below sea level in this region. The station lies near the track of cyclones that move onto the polar plateau from the Ross and Weddell seas, bringing intrusions of relatively warm maritime air and giving rise to stronger winds, heavier precipitation, and greater temperature fluctuations than might otherwise be expected at a location so deep in the interior of the Antarctic.

The relatively strong winds and frequent blizzards resulted in heavy drifting and accumulation of snow in the camp area, creating particular problems for the meteorological program. Among these were the need for a specially constructed tower for the radome housing the detection equipment for upper-air soundings; the frequent need to clear snow from the overhead release doors of the rawinsonde balloon tower; and the necessity to dig out and re-position outside equipment, such as the instrument shelter, ceiling light projector, radiation instruments, and precipitation gauge.

Tables 1 and 2 present some of the surface data from the first three years of observations (including the IGC-59 period) at Byrd Station. The large year-to-year fluctuations in mean temperature for the same month are particularly striking. In August 1957, the mean temperature was —18.8° F, highest for any of the seven months from March to September; in August 1958, however, the mean temperature was —44.0° F, making it the coldest month of that year. In 1959, the mean August temperature was —38.8° F.

The warmth of August 1957 was related to the surface circulation regime in that month, when many pressure lows, with their accompanying warm maritime air, moved from the Ross Sea to the Weddell Sea along tracks over or very near Byrd Station. In August 1958, on the other hand, the storm tracks were well north of Byrd Station and cold plateau air predominated, a fact reflected also in the low precipitation in August 1958 as compared with August 1957. The temperature regime of August 1959 was

Table 1. *Temperatures (°F) at Byrd Station in 1957, 1958 and 1959.*

| Month | Mean | | | Maximum | | | Minimum | | |
|---|---|---|---|---|---|---|---|---|---|
| | '57 | '58 | '59 | '57 | '58 | '59 | '57 | '58 | '59 |
| Jan | + 4.1 | +13.3 | − 0.8 | +22.3 | +23.7 | +14.4 | −21.3 | −11.0 | −17.7 |
| Feb | − 6.2 | − 5.2 | − 1.8 | +11.5 | +19.4 | +16.0 | −34.8 | − 3.6 | −10.8 |
| Mar | −22.9 | −18.4 | −13.7 | − 0.9 | + 7.9 | + 7.9 | −40.1 | −53.1 | −44.0 |
| Apr | −32.4 | −23.4 | −11.0 | + 0.1 | +15.4 | +19.0 | −68.1 | −65.4 | −49.2 |
| May | −32.4 | −18.9 | −28.5 | +19.6 | +12.0 | +18.1 | −66.5 | −66.6 | −65.9 |
| June | −28.3 | −41.4 | −27.0 | + 3.6 | − 3.6 | − 5.1 | −70.4 | −75.5 | −54.8 |
| July | −41.3 | −41.3 | −29.9 | − 5.1 | +13.5 | + 7.2 | −69.9 | −81.8 | −66.3 |
| Aug | −19.8 | −44.0 | −37.8 | + 8.2 | + 0.9 | − 4.7 | −51.3 | −80.0 | −70.1 |
| Sep | −23.1 | −40.2 | −32.4 | + 1.4 | − 6.0 | − 2.6 | −61.4 | −65.0 | −64.5 |
| Oct | −15.0 | −22.2 | −30.1 | +11.8 | + 5.0 | − 2.9 | −54.8 | − 9.2 | −59.1 |
| Nov | − 5.1 | − 5.6 | − 8.7 | +24.1 | +10.4 | +13.8 | −28.5 | −28.1 | −38.9 |
| Dec | +10.2 | + 1.0 | + 5.2 | +24.1 | +27.1 | +17.1 | −13.4 | −21.8 | − 9.0 |
| Year | −17.7 | −19.7 | −18.0 | +24.1 | +27.1 | +19.0 | −70.4 | −81.8 | −70.1 |

Table 2. *Winds and Precipitation at Byrd Station in 1957, 1958, and 1959.*

| Month | Prevailing wind direction and speed (knots) | | | Fastest wind (mph) | | | Precipitation (inches of water equivalent) | | |
|---|---|---|---|---|---|---|---|---|---|
| | '57 | '58 | '59 | '57 | '58 | '59 | '57 | '58 | '59 |
| Jan | N 10.5 | NNE 13.1 | NNE 12.0 | 28 | 32 | 36 | 1.24 | .43 | .06 |
| Feb | N 12.5 | NNE 18.7 | N 13.6 | 31 | 58 | 40 | .77 | T* | .39 |
| Mar | NE 17.2 | N 14.0 | NNE 15.7 | 42 | M | 53 | .86 | .08 | .03 |
| Apr | NNE 17.3 | NNE 14.9 | N 14.3 | 43 | 52 | 52 | .72 | .29 | .14 |
| May | NNE 16.5 | NNE 19.0 | NE 15.5 | 34 | 61 | 59 | .96 | .21 | .13 |
| June | N 15.5 | N 12.3 | NNE 17.1 | 47 | 44 | 60 | 1.97 | .01 | .12 |
| July | NNE 19.0 | N 15.7 | N 16.3 | 45 | 63 | 67 | 2.73 | .03 | .10 |
| Aug | N 23.5 | NNE 15.9 | NNE 18.6 | 62 | 61 | 59 | 1.50 | T | .12 |
| Sep | NE 22.5 | NNE 20.0 | NE 18.4 | 46 | 58 | 63 | 2.79 | T | .09 |
| Oct | N 15.0 | NNE 18.6 | NE 14.9 | 44 | 52 | 45 | 3.24 | .03 | T |
| Nov | NE 16.5 | NNE 17.1 | NNE 14.3 | 42 | 58 | 41 | .05 | T | T |
| Dec | N 13.4 | NNE 13.3 | NE 11.5 | 50 | 40 | 36 | .05 | .65 | .03 |
| Year | N 16.6 | NNE 16.1 | NNE 15.2 | 62 | 63 | 67 | 16.88 | 1.75 | 1.21 |

*Trace amount

similar to that of August 1958. Temperatures in August 1957 also fluctuated rapidly on a day-to-day basis, reaching +8.3° F on the 29th and then dropping rapidly to a low of —51.2° F on the 30th.

As shown in Table 2, winds at Byrd Station, prevailingly from the north-northeast, average about 15 knots and reach gale force in nearly every month. It was observed also that winds of 20 knots or greater (which occur more than 2/3 of the time) are sufficient to start the snow drifting and that winds of 30 knots or greater (which occur about 1/3 of the time) result in blizzard conditions with near-zero visibility. Thus, the problem of drifting snow was worse at Byrd than at any other US scientific station in the Antarctic.

There was evidence, at times, of an apparent katabatic (downslope) wind flow at Byrd Station, particularly during the winter of 1958. Traverse parties have determined that the surface elevation rises gently north-northeastward from the station and falls toward the southwest—for a total drop of about 4000 feet in 300 miles; the prevailing winds are from north to northeast throughout the year. During periods of clear weather, there were times when a fairly brisk northerly wind (15–20 knots) decreased to almost calm about 1500 feet above the surface. Thus, it seems probable that, when clear skies extend toward the north, the additional radiational cooling at the slightly higher elevations in that direction from the station would be enough to create a relatively colder layer of air near the surface, which would then flow downslope (southward) as a gravity wind.

When blizzard conditions occurred at temperatures lower than about —30° F at Byrd Station, a high static electricity charge was seen to build up on buildings and guy wires, with brilliant blue-white arcing visible during the dark period. The static sometimes seriously impaired radio communications, and also presented a danger to those working with the inflammable hydrogen used to inflate the radiosonde balloons, although no mishaps occurred.

The lowest temperature recorded by upper-air soundings during 1957–58 was —83° C (—135° F), on July 20, 1958. In winter, particularly in July and early August, the tropopause tended to weaken, or even disappear entirely; with the return of the sun, it again became easily identifiable, usually between the 300- and 200-millibar levels (approximately 30,000–38,000 feet). The pattern of rapid spring stratospheric

warming noted at other Antarctic stations also prevailed at Byrd Station. In 1957, temperatures at a height of about 12 miles above sea level (50-millibar pressure level) rose from —70° C (—94° F) in mid-October to —27° C (—17° F) by November 6, an increase of over 75° F in less than a month. In 1958, warming was similar but slightly less pronounced, with 50-mb temperatures rising from —70° C in mid-October to —30° C by November 10.

Extremely brilliant optical phenomena, many caused by ice crystals at low levels, were also observed at Byrd Station. Double halos and parhelia were common, and both tangential and circumzenithal arcs occurred frequently. (Halos appear as colored or whitish rings and arcs about the sun or moon and are produced by refraction by or reflection from ice crystals in the atmosphere. Parhelia are colored, luminous spots 22° or more laterally from the sun; tangent and circumzenithal arcs are types of halos, the former tangent to other halos and the latter usually appearing about 46° above the sun.)

One of the most interesting of these optical displays occurred in May 1958, when a combination of ice crystals aloft and a water-droplet fog to the south caused a bright halo around the full moon as well as a circumzenithal arc, which, to the south, intersected a moonbow (rainbow formed by moonlight).

# International Geophysical Calendar, 1962

*The following is taken from a brief explanatory text accompanying the International Geophysical Calendar for 1962, issued by the International World Days Service, A. H. Shapley, Spokesman. The 1961 Calendar, accompanied by an expanded text describing its purpose and how it is used, was published in* Bulletin No. 42. *A report on the plan for Alerts and Special World Intervals during 1961–62 appeared in* Bulletin No. 47.

The International Geophysical Calendar for 1962 (Fig. 4) designates selected days and intervals for special geophysical experiments and analyses during 1962, and is thus a framework for world-wide coordination. It serves mainly those branches of geophysics dealing with atmospheric phenomena that vary significantly during the course of a year. For some studies, such as the routine recording of geomagnetic-field variations, the programs of observatories are normally carried out at a uniform level throughout the year, and the Calendar is therefore not needed. However, in many other studies—rocket experiments, for example—in which it is not practical or meaningful to carry out the same program every day, the Calendar can provide a useful mechanism for international coordination. Experimenters in many countries, laboratories, and disciplines tend to carry out their experiments on days or intervals marked on the Calendar. Results may then be more easily and usefully compared.

In some scientific fields, international organizations have made specific recommendations for investigations on days or intervals marked on the Calendar. In others, the arrangements are informal or self-evident. Some examples are given below.

### Regular World Days (RWD)

These days (three consecutive days each month) are intended for observations, analyses, or special experiments which, as a practical matter, can be carried out only about 10% of the time and should, for

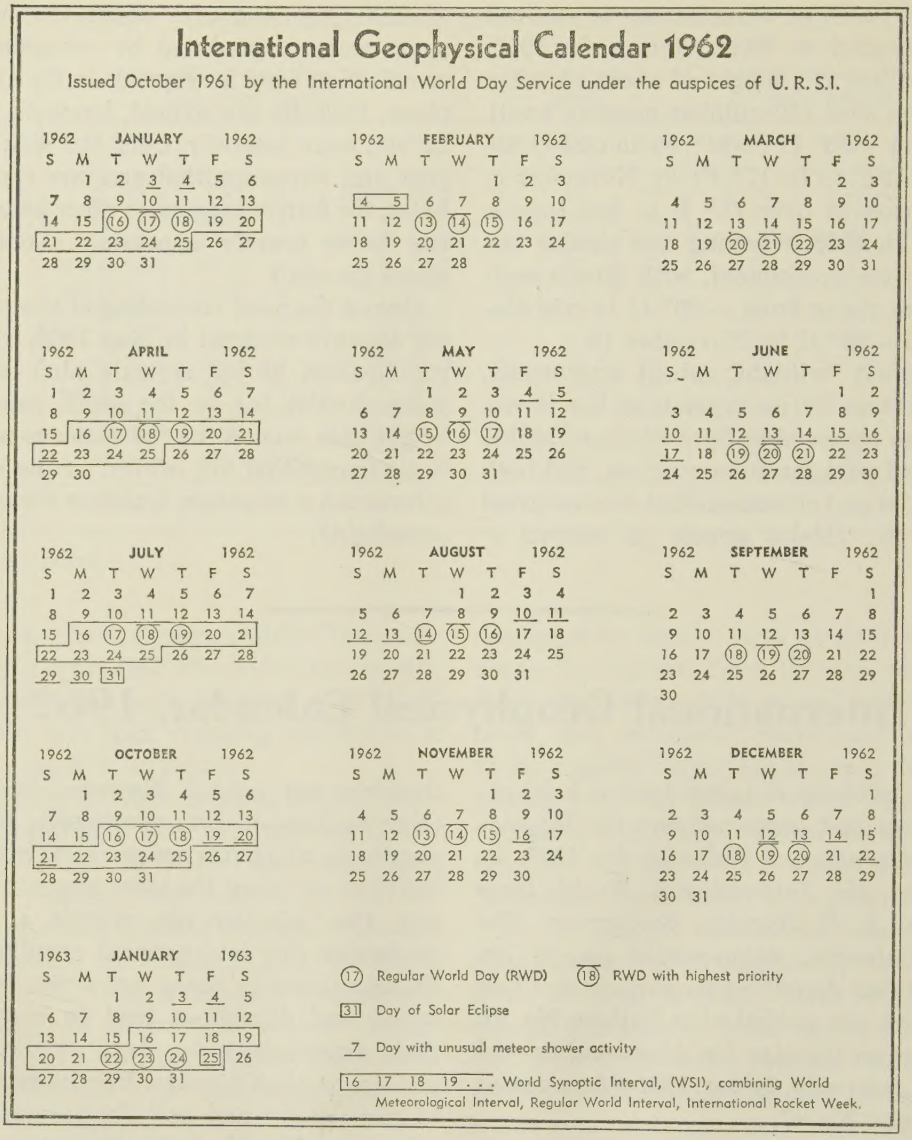
International Geophysical Calendar 1962
Issued October 1961 by the International World Day Service under the auspices of U. R. S. I.
1962 JANUARY 1962
1962 FEBRUARY 1962
1962 MARCH 1962
1962 APRIL 1962
1962 MAY 1962
1962 JUNE 1962
1962 JULY 1962
1962 AUGUST 1962
1962 SEPTEMBER 1962
1962 OCTOBER 1962
1962 NOVEMBER 1962
1962 DECEMBER 1962
1963 JANUARY 1963
(17) Regular World Day (RWD)
(18) RWD with highest priority
31 Day of Solar Eclipse
7 Day with unusual meteor shower activity
16 17 18 19 . . . World Synoptic Interval, (WSI), combining World Meteorological Interval, Regular World Interval, International Rocket Week.

Fig. 4. *IWDS International Geophysical Calendar for 1962.*

maximum usefulness, be spaced evenly throughout the year. The RWD's with highest priority are for similar kinds of studies that can be undertaken for only one day each month.

## World Synoptic Intervals (WSI)

These Intervals are intended for experiments which, for practical reasons, cannot be performed continuously, but for which statistics of seasonal variations are especially needed. To simplify the Calendar, the Regular World Intervals, World Meteorological Intervals, and International Rocket Weeks of past years have been combined for 1962 into this one set of WSI. For purposes of the synoptic meteorological rocket programs, as designated by COSPAR and WMO (see *Bulletin No. 40*), the Intervals have been placed about a month after the equinoxes and solstices—

the times of marked seasonal change in certain upper-air meteorological phenomena.

During WSI, meteorological rockets are launched at least once daily over a network of stations. Balloon sounding programs, either with special instruments or involving launchings to unusually high balloon altitudes, have been planned for WSI. Ionospheric-drift and high-atmosphere-wind measurements, are other examples of suitable programs for such Intervals. In several disciplines, WSI data will provide a sampling of variations throughout the year, but with improved statistics during one month of each season.

## Other Special Days

Also marked on the 1962 Calendar are other special days, including the days of solar eclipses (two in 1962 and one in January 1963), when special programs may be expected to be carried out in appropriate parts of the world to study the sun and any eclipse effects on the earth's atmosphere. Ionospheric stations customarily increase their observing programs on these days, even if the magnitude of the eclipse at their locations is small, and many solar-activity observatories make extra observations and issue specially detailed reports to assist in interpretation of the geophysical effects.

Also shown on the Calendar are days when unusual meteor-shower activity is expected. These include some of the important visual meteor showers and also unusual showers observable mainly by radio and radar techniques. Attention is called to these days also because ionization produced by meteors may account for unusual effects in other geophysical experiments.

The Annual World Meteorological Day, scheduled for March 23 but not marked on the Calendar, was first held in 1961. Its purpose is to make the activities of the World Meteorological Organization, and the services that national meteorological services can render to the various branches of economic development, better known and appreciated by the public.

*Other Special Intervals Not Appearing on Calendar:* Periods of great magnetic, auroral, and ionospheric disturbance are also of considerable geophysical interest. Worldwide coordination of observations is especially useful for stations not near the auroral zones, i.e., those at which the beginning of a major disturbance may not be immediately apparent from local observations. Notices of Geophysical Alerts and Special World Intervals (SWI) are distributed by telegram or radio broadcast on a current basis by the solar-geophysical Regional Warning Centers. (See *Bulletin No. 47* for addresses of these Centers and for details of the aims, functions, and methods of operation of the World Warning Agency.)

Many geophysical stations increase their programs or carry on special experiments during such periods of solar-terrestrial disturbance. Prompt notification of immediately significant geophysical observations and of major solar-flare events having important and sometimes long-lasting geophysical effects are also undertaken through the Regional Warning Centers.

## Additional Information

The 1962 Calendar was drawn up by A. H. Shapley and J. V. Lincoln, of the US National Bureau of Standards, Boulder Laboratories, Boulder, Colorado, in consultation with interested ICSU unions and committees and representatives of the WMO. A fuller description of the Calendar has appeared in the *U. R. S. I. Information Bulletin* and in various widely available scientific publications. Supplementary copies may be obtained from the Secretary General of URSI, 7 Place Emile Danco, Brussels 18, Belgium.

# Biological Oceanography in the North Polar Sea from IGY Drifting Station Alpha, 1957-58

*The following material, prepared by the* Bulletin *staff, is based on a report by T. Saunders English, Department of Oceanography, University of Washington, entitled* Some Biological Oceanographic Observations in the Central North Polar Sea, Drift Station Alpha, 1957-1958, *and published by the Arctic Institute of North America as its Research Paper No. 13 (also as Air Force Cambridge Research Laboratories Scientific Report No. 15, AFCRL-652), April 1961.*

Because only a very limited amount of light is available to the Arctic Ocean submarine environment, primary production—the production of phytoplankton, simple forms of floating plant life that provide the basic food resource for marine animal life—is very low compared to that in other oceans, and the productive season is short. For these reasons, and because of the remote, rigorous, and hazardous nature of the Arctic Ocean area, substantial gaps have existed in our knowledge of its marine life. Thus, when the establishment of a US-IGY scientific station on Drifting Station Alpha provided the opportunity, a series of biological oceanographic observations was conducted in the central Arctic Ocean during the period of occupation of the station, April 1957-November 1958. Major aims of these investigations were to study various aspects of primary productivity and to obtain, in water bottles, a series of samples of Arctic Ocean phytoplankton in their natural environments.

(Earlier *Bulletins* report on Station Alpha programs and results, and include maps showing its drift path; *Bulletin No. 17* provides some background on the marine biology studies, and *Bulletin No. 27* reports on similar studies on IGY Drifting Station Bravo, elsewhere in the Arctic Ocean.)

## The Ice Flow Environment

Drifting Station Alpha was located on a large ice floe in the permanent Arctic ice pack. The station's course during its period of occupation remained in about the center of the Arctic Ocean, near the "Ice Pole," or "Pole of Inaccessibility." Floes of the permanent ice pack average about 2.5 meters thick; ridges of broken ice (hummocks), mostly up to 3 meters high, may reach 10 meters. Much of the floe area near Station Alpha was 3 meters thick, and small areas were observed during dives beneath the floes (using self-contained underwater breathing apparatus) in which several thicknesses of floe reached a depth of about 15 meters. Little change in thickness was seen during the melt season as ablation was slight: 7-10 cm in 1957 and 30 cm in 1958.

Leads—channels of open water between the floes—have been estimated to constitute only about 1% of the total surface area within the ice pack. The first lead examined in the Station Alpha studies opened on June 15, 1957, and its surface ceased to freeze in late June. At the end of August, slush began to form in open leads. There is less open water toward the center of the ice pack and progressively more toward the outer edges. For more than 10 months of the year, the floe ice is covered by wind-packed snow. Ablation begins after the return of the sun each year, eventually removing the snow cover and melting some of the floe ice, leaving a granular ice surface.

Melt-water ponds appeared on the floes in early July in both 1957 and 1958 and eventually covered 15-30% of the surface area. The melt water runs off the floes into cracks and leads, forming a surface layer of nearly fresh water 1-2 meters deep; the thickness of this layer varies with the size

of the watershed, intensity of melting, floe movement, wind-driven mixing with the underlying sea water, and extent of the leads. Pond surfaces froze in late August and the entire area became covered with the snow of the new winter. Investigation of the effects of these seasonal changes on the biological and hydrographic cycles was a major part of the field studies.

## Vertical Distribution of Water Masses

The details of surface and deeper circulation of the North Polar Sea have been rather fully described by earlier workers. Results from IGY Drifting Station Alpha agree with these descriptions and add some details to our knowledge of the surface water mass. Temperature and salinity, and the derived density, may be used to differentiate the water masses (Fig. 5). The uppermost layers consist of Arctic Upper Water, of low salinity and temperature, and, below it, Arctic Intermediate Water, with generally increasing temperatures and a sharp halocline (zone of rapidly increasing salinity, and of density, just below the surface layers) ranging from about 31 per mille (31 parts per thousand) at a depth of 50 meters to more than 34 per mille at 200 meters. Warmer Atlantic Water, bounded at its upper and lower surfaces by the 0° C isotherms, lies below the Arctic Intermediate Water and above the Arctic Deep Water, which extends to the ocean bottom.

A Pacific Ocean Water stratum, intruding between the Arctic Upper Water and Arctic Intermediate Water, having an estimated temperature range of —0.7 to —1.2° C and a salinity of about 32 per mille, was recognized a few years ago. More recently, it has been suggested that the intrusion of Bering Sea Water into the Arctic Ocean, and the mixing of this water with appropriate amounts of shelf water in summer and winter, is responsible for both the temperature maximum in the North Polar Sea (here, at 75–100 meters) and the

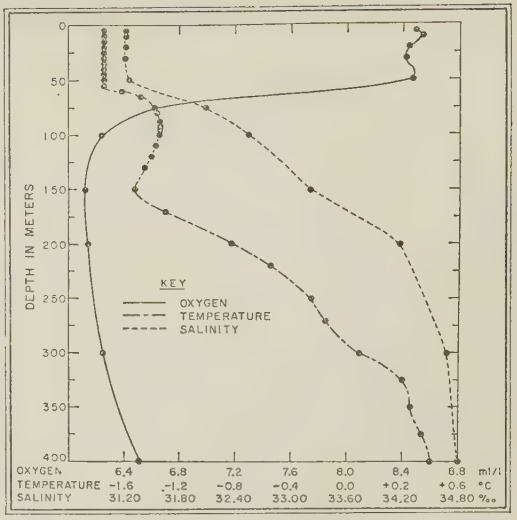


Fig. 5. *Temperature, Salinity, and Dissolved-Oxygen Variation with Depth, Drifting Station Alpha, June 23–24, 1958.*

temperature minimum below it (here, at 150 meters). This interpretation is strongly supported by the vertical distribution of dissolved oxygen and of inorganic nutrients observed from Station Alpha (Figs. 5 and 6).

The vertical homogeneity of observed oceanographic variables in the Arctic Upper Water, as well as the rapid attainment of uniform temperature and salinity with depth, indicate that mixing in this stratum is rapid and complete. Nutrient enrichment of the Arctic Upper Water must proceed very slowly, however, as the pronounced halocline is a strong barrier to upward mixing of nutrients from the maxima observed at 100–150 meters in the Pacific Ocean Water (Fig. 6). Also, a persistent temperature minimum (about —1.7° C) between the Arctic Upper Water and the Pacific Ocean Water, seen in temperature profiles for 1958, suggests that there is no mixing across that isotherm during the summer, although in some years this barrier may be broken.

## Seasonal Cycles

As summer progressed, salinity decreased slightly in the Arctic Upper Water (several

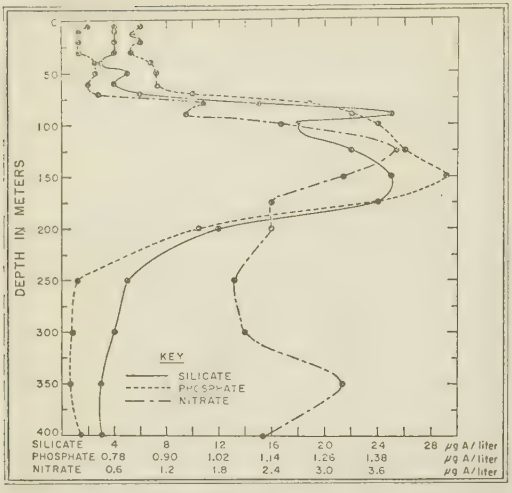


Fig. 6. *Variation of Inorganic-Nutrient Concentrations with Depth, Drifting Station Alpha, August 19, 1958.*

tenths of 1 per mille), temperature increased slightly (several tenths of 1° C), dissolved oxygen increased, and the amount of solar radiation penetrating into the ocean increased very noticeably. If it is assumed that the size of the phytoplankton population can be estimated from the concentration of chlorophyll *a*, the population was ten times as large in late July and early August as it was in early June. (Chlorophyll *a* is the first photosynthetic pigment to develop when light is supplied in a dark environment.) Carbon-14 experiments using samples representing most of the 1958 productive season indicate that the photosynthetic potential of the phytoplankton varies in a manner similar to that of the chlorophyll *a* concentration. The observations were inadequate to demonstrate any decrease in inorganic nutrients caused by the production of phytoplankton.

Previously, in studies near the periphery of the permanent ice pack northeast of Greenland, seasonal variations in phytoplankton concentrations were noted only in the upper 25 meters, which is in accord with other observations showing that Arctic Upper Water extends to a depth of 20–30 meters in southern parts of the sea and 50–75 meters in the north. Seasonal changes were also noted in the zooplankton (floating or weakly swimming, minute animal life), which remained in the "winter state" in July. The exceedingly short productive season makes this an extreme example of a monocyclic sea.

Station Alpha results indicate that the seasonal cycle occurred to a depth somewhat below 50 meters, and results from Fletcher's Ice Island (A. E. Collin, 1959, and J. S. Farlow, 1958) and from the Soviet station North Pole II show a similar layer over a large portion of the North Polar Sea. Complete mixing of the Arctic Upper Water ensures that this seasonal cycle will be evident to whatever depth the layer extends in other areas.

## Incident and Submarine Solar Radiation

Daily insolation, or incident solar radiation, even as far south as 70° N, is negligible from early November to early February. It increases rather uniformly into May, reaches a maximum about June 21, and then decreases through the summer and autumn. The seasonal trend of visible radiation at Drifting Station Alpha was clear despite a variability related to differential cloud cover (Fig. 7).

The amount of visible radiation available for photosynthesis beneath the ice is increased by the occurrence of leads, by ablation of the snow cover, by decrease in ice-floe thickness, by formation of melt water ponds on the floes, and by decrease in the albedo (percentage of incident radiation that is reflected) of the ice surface. In June, before the snow cover had disappeared, less than 1% of the surface radiation penetrated through an average ice floe into the sea. Removing a layer of snow only a few centimeters thick more than doubled the amount, and wetting the surface increased it still more. In mid-July, the radiation under a pond was about five times as high as that under ordinary ice-floe areas.

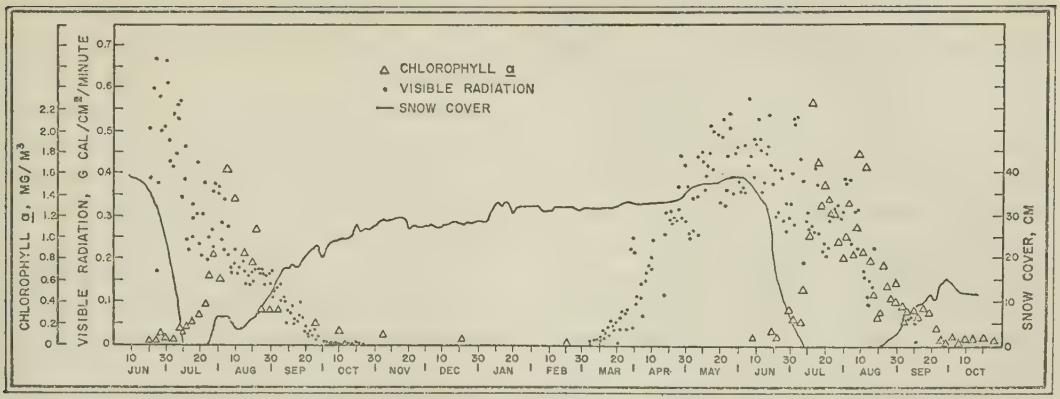
CHLOROPHYLL a
VISIBLE RADIATION
SNOW COVER
CHLOROPHYLL a, MG/M³
VISIBLE RADIATION, G CAL/CM²/MINUTE
SNOW COVER, CM
JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT

Fig. 7. *Comparison of Visible Radiation, Snow Cover, and Chlorophyll* a *Concentration, Drifting Station Alpha, 1957–1958.*

Submarine radiation was measured at successive depths, both in large leads and beneath ice floes. The vertical distance between equal radiation intensities provides a rough measure of the depth by which the zone in which plants thrive is changed from one environment to the other. It appears that an average floe reduces this depth to less than one-half that of the freely convective layer of Arctic Upper Water.

The snow cover vanished in early July, greatly increasing the amount of light entering the sea (Fig. 7) and more than compensating for the decrease of sunlight at the surface following the peak about June 21. Maximum penetration of light into the sea must occur shortly after the formation of ponds on the floe surfaces.

The decrease in submarine radiation in August is quite abrupt, and is caused by the lowering of the angle of incidence of solar radiation and an increase in albedo brought about first by freezing of ponds and leads and finally by the new snow cover.

The fact that chlorophyll *a* increased, and reached maximum concentration, after the widespread formation of melt-water ponds and while the final traces of snow were disappearing, confirms the belief that photosynthesis under the ice pack is limited by the lack of sufficient solar radiation. The role of the ice pack in regulating the amount of solar radiation penetrating into the sea is also clear. This amount must depend, during a productive season, on the proportions passing through leads and floes, with or without ponds or snow cover; on seasonal, diurnal, and meteorological variations; and on the variability of the ice cover and its movement relative to the ocean. Thus, the history of the radiation received by any small volume of sea water is always in doubt, and some of the unusually high and low chlorophyll *a* values obtained can probably be explained by a radiation history widely divergent from the average.

## Distribution of Chlorophyll *a*

Seasonal variations in chlorophyll *a* concentration were followed through two productive seasons and the distribution with depth was considered for periods throughout the 1958 season. Figure 8 shows this distribution in the depth range of 4–64 meters. In samples collected at depths of 128 and 256 meters, only traces were found.

The shapes of the concentration curves must reflect the balance between production and both mixing and sinking of the phytoplankton cells. Before June, produc-

tivity must have been low enough for mixing in the Arctic Upper Water to maintain an almost homogeneous distribution of chlorophyll *a* with depth. As the productive season progressed into July, the concentration near the bottom of the ice pack reached a pronounced peak, indicating that production was proceeding faster than mixing and sinking. In August, maximum values occurred deeper in the water column, reflecting a decrease in productivity and the effects of sinking and mixing. When the productive season was over, the concentration of chlorophyll *a* in the water column was again almost homogeneous.

### Plankton Samples

During each week of the productive season, a phytoplankton sample was concentrated in a net for comparison with a routine sample taken with a molecular filter. The net retained only trace quantities of chlorophyll *a*, and at the time of maximum concentrations the amount captured by the net was less than 10% of the amount retained on the filter. A preliminary examination of preserved samples indicates that few large diatoms were present but that small flagellates were numerous. This result was expected on the basis of previous work by others.

### Production in Leads and Ponds

Earlier investigators suggested that the small amount of open water between ice floes was not of major importance to phytoplankton production in the North Polar Sea; it appeared necessary, however, to establish the relation of that water to the main body of the ocean.

In many samples taken in a lead, in 1957, the integrated concentration of chlorophyll *a* for a one $m^2$ water column extending from the surface to a depth of 5 meters was consistently about one-half the concentration found from 5 to 20 meters. Although the leads received strong sunlight through July, chlorophyll *a* concentrations were not high until August. Each sample was tested to determine whether it was fresh, brackish, or salty. The surface water was fresh during July, but in August, runoff from the floes had abated and the wind had mixed the fresh layer with the ocean below.

In 1958, chlorophyll *a* profiles were taken in leads and through a hole in the floe. Surface concentrations in leads were always smaller than those deeper in the leads, and usually smaller than the concentration beneath the ice floes. Carbon-14 experiments in 1957 and 1958 showed a similar pattern of photosynthesis and photosynthetic potential with depth.

The low concentrations of chlorophyll *a* at the surface are thought to reflect the dilution of surface sea water with freshwater runoff, but inhibition of photosynthesis by strong surface light could also contribute to the observed effects. However, the high surface chlorophyll *a* concentrations in early August 1957, when runoff had diminished, suggests that dilution is the major factor. A single sample from a fresh-water floe-surface pond showed only a trace of chlorophyll *a*, and no color was ever seen in a pond. Although water in the leads sometimes attained high chlorophyll *a* concentrations and showed higher photosynthetic potential than water below the depth of the ice bottom, little effect of increased solar radiation through the leads was immediately evident.

On one occasion, a sample of what appeared to be a plankton bloom was taken with a large syringe during a dive through a lead. The concentration of chlorophyll *a* measured in the sample was well above that of the main body of the ocean at that time but similar to concentrations in other such areas in August.

E. H. Gran, reporting in 1904 on samples collected during the *Fram* expedition (the research vessel *Fram* crossed the Arctic Ocean basin frozen in the ice pack, in 1893–96) mentions free-floating lumps of

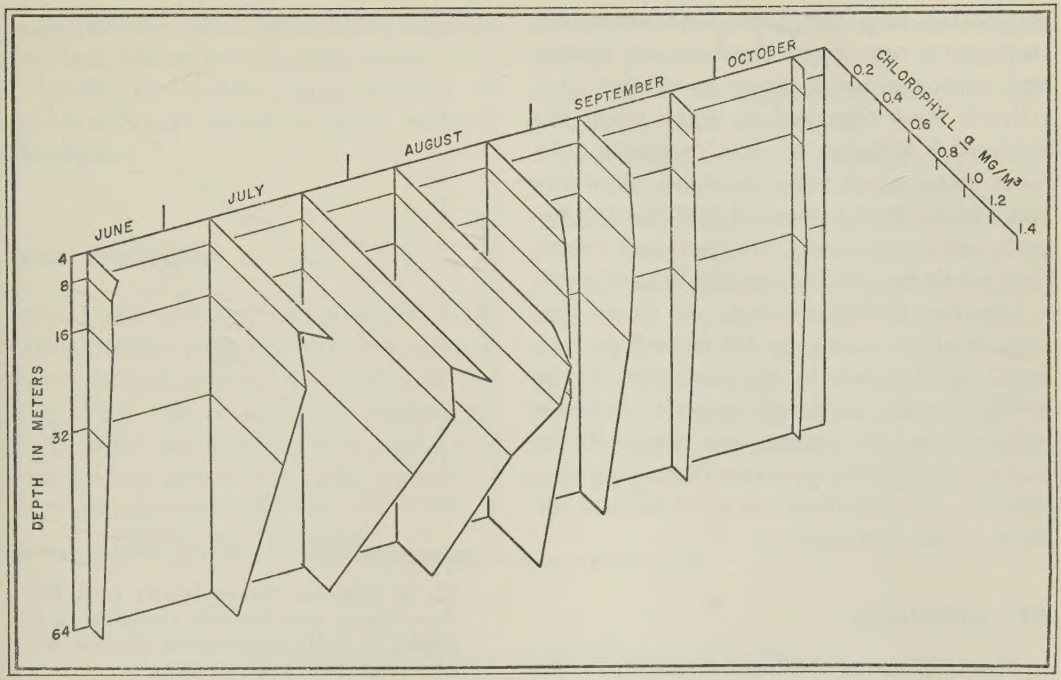


Fig. 8. *Chlorophyll a Concentrations with Depth during 1958 Productive Season at Drifting Station Alpha.*

planktonic algae in leads; diatoms on the "ice foot" (a ledge projecting from a floe just below the comparatively warm few cm of surface water, which more thoroughly melts away the overlying floe ice); and diatoms in cylindrical holes on floes, at the bottoms of fresh-water ponds not connected with the open sea.

In 1957, free-floating lumps of planktonic algae were observed near Drifting Station Alpha. In 1958, one area of ice foot was discovered in a persistent lead; clumps of diatoms on it had melted cylindrical holes into the ice. A few bleached clumps of diatoms were also discovered on the ice-floe surfaces and on the bottoms of ponds. No pigmented diatoms were found in these places, however, and it seems likely that the bleached clumps once floated in leads or were on the bottoms of floes, and that they then became frozen into floes and finally moved upward to the floe surfaces as the floes underwent ablation at the top and accretion at the bottom.

## Inorganic and Organic Nutrients

Inorganic nutrients are less abundant in the Arctic Upper Water than in the Pacific Ocean Water, but there is no evidence that a shortage of such nutrients limits production in the North Polar Sea, since their experimental addition in carbon-14 experiments failed to lead to a significant increase in photosynthesis.

Trygve Braarud, in 1935, pointed out that the fresh water from melting ice is very low in nutrients, and would limit rather than increase plant production. In the Station Alpha studies, measurements made of inorganic nutrient from a pond, a lead, and at depths in the sea, also demonstrate that melt water can only dilute the Arctic Upper Water.

Films of organic matter, predominately diatoms, but probably including flagellates, ciliates, bacteria, and organic detritus, can be seen on the sides and bottoms of ice floes. These films must sometimes be in-

corporated into the floes, both when the melt water runs under the floes and freezes and when the ice thickens in winter. Amphipods were observed to graze along the sides and bottoms of floes, appearing to wear away small volumes of ice. Observations while diving revealed that the amphipods are occasionally trapped and frozen into a hole by new ice forming behind them.

Organic inclusions such as those discussed above must be infrequent and of small significance in the economy of the Arctic Ocean. Although organic nutrients released by ice melting are not likely to contribute directly to photoautotrophic production, such detritus can serve as food for some of the zooplankton.

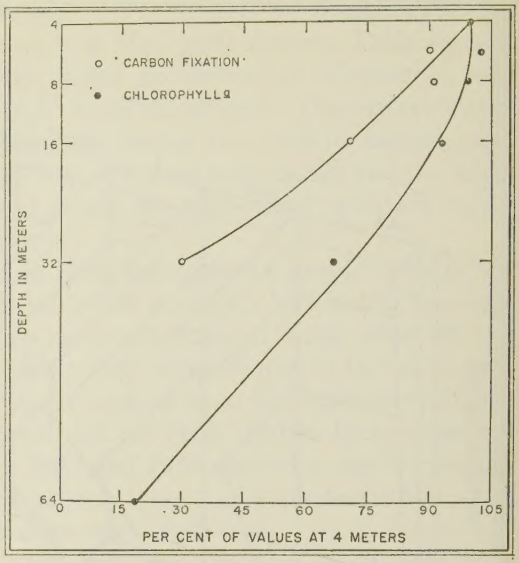


Fig. 9. *Relative Photosynthesis from Six Experiments with Samples Collected at a Depth of 6 Meters, Drifting Station Alpha, July 20–August 13, 1958.*

## Photosynthesis

The carbon-14 technique was used on 1957 samples to obtain a rough estimate of photosynthesis *in situ* beneath the surface of a lead. There was no measurable photosynthesis on July 1, but for late July and mid-August, it is estimated that, in a one-$m^2$ water column extending to a depth of 30 meters, 5–6 milligrams of carbon were assimilated per day. The water column in the lead above the bottom of the ice floes contributed about one-fourth to the totals.

In 1958, the photosynthetic potential of water from different depths was studied. The decrease of photosynthetic potential with depth was found to be similar to, but more rapid than, the decrease of chlorophyll *a* concentration with depth (Fig. 9). There are several possible explanations for this difference in rates of decrease: if phytoplankton from greater depths had become adapted to lower light intensities the illumination used in the experiments might then have inhibited photosynthesis; also, the proportion of photosynthetically inactive pigment (included here with chlorophyll *a*) might increase with depth.

Studies were conducted of the effect of different light intensities on 14 species of marine plankton algae from sub-samples of water obtained at a depth of 6 meters. The compensation intensity (light-intensity level at which plant metabolism balances the energy produced by photosynthesis) was between 20 and 200 foot-candles and the saturation intensity (light intensity above which there is no further increase in photosynthesis) was near 2000 foot-candles. It seems especially significant that the phytoplankton population under the ice does not show adaptation to lower light intensities than do similar organisms from lower latitudes, examined previously by others.

A determination of the ratio of photosynthesis to chlorophyll *a* concentration in samples taken from a depth of 6 meters, on the same or consecutive days, gave a value of 0.6, considerably lower than the value of 3.7 obtained in studies by J. H. Ryther and C. S. Yentsch, in 1957. The lower ratio in the Station Alpha studies may result from the extremely low temperature of the Arctic Upper Water, which may reduce the efficiency of carbon fixation per unit of

chlorophyll *a*. (This explanation, though convenient, raises considerable doubt; further work, or another interpretation of these data, may supply a more suitable explanation.)

### Annual Production

Investigations conducted from IGY Drifting Station Alpha in 1957–58 indicate that the annual primary production in the North Polar Sea is very low relative to that of other ocean areas. The productive season is short and all indices of productivity are low. The limiting amount of submarine illumination serves as a satisfactory first order explanation for this low level of primary production.

Because primary production in the North Polar Sea is so low, further refinements in methods of estimating the annual total appear unnecessary. The factors operating to produce and maintain a population of photosynthetic organisms under the extreme environmental conditions observed will continue to be of interest, however. In this report, the behavior and special adaptations of the phytoplankton population have been suggested rather than explained.

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# A Further Note on Cosmic-Ray Air Showers

A brief report entitled "Energetic Cosmic-Ray Air Shower," in *Bulletin No. 51,* September 1961, may contain an unintended implication that cosmic rays of extragalactic origin are exceedingly rare. The report describes an extremely energetic cosmic-ray air shower detected at the Massachusetts Institute of Technology cosmic-ray station, Volcano Ranch, New Mexico, and reports the investigators' conclusion that the primary cosmic-ray particle that caused the great air shower had an energy of $10^{19}$ electron volts, or more, and that it appears certain that this energy must have been acquired outside our galaxy.

A note in *Physical Review Letters,* May 1, 1961, by John Linsley, Livio Scarsi, and Bruno Rossi, served as the primary basis for the *Bulletin* report; although this note was not the source of statements possibly leading to this erroneous implication, Dr. Linsley, Director of the Volcano Ranch Station, has kindly offered the following further clarification, which expresses the view of most current workers in this field: "If extragalactic cosmic rays exist, they probably exist in some quantity, with energies less than $10^{19}$ ev, as well as greater. Probably *most* of the cosmic rays with energies greater than $10^{18}$ ev (some would say $10^{17}$) are also extragalactic. Extragalactic cosmic rays with energies lower than $10^{17}$ or $10^{18}$ ev, if they exist, would not be distinguishable from the background of cosmic rays of galactic origin."

The *Bulletin* report states, also, that ". . . the total number of particles [in the air shower] was at least 5.5 billion, and may have been 4 to 8 times that many." The estimate "4 to 8 times" resulted from an editorial error and should be corrected to read ". . . may have been *twice* that many."

Subsequent to the event discussed above, the Volcano Ranch Station, using a detector array covering about four times the area of the earlier array, detected a still larger and more-energetic cosmic-ray air shower. The Volcano Ranch investigators calculate

that this shower, which occurred in March 1961 and was the largest recorded as of that time, consisted of about 32 billion particles and was triggered by a primary cosmic-ray particle having an energy of $6 \times 10^{19}$ ev.

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